Astron. & Astrophys. 31, 459 – 460 (1974)

On Pottasch's Interpretation of the Interstellar Na I/Ca II Ratio

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Received April 4, 1973

Summary. The interpretation of the interstellar Na I/Ca II ratio given by Pottasch (1972b) leads to the prediction of Ca I absorption in conflict with observation.

Key words: interstellar matter – abundances

The Na I to Ca II column density ratio derived from optical interstellar lines varies by three orders of magnitude. This large variation may reflect differences in the Na and Ca abundances; but, as shown by Routly and Spitzer (1952), it could result entirely from variation of interstellar ionization conditions. Pottasch (1972b) has further explored the consequences of the latter possibility. Using the observed H I, Na I, Ca I and Ca II column densities, he derived the abundance ratios [Na/H] and [Ca/H] for four interstellar clouds[1]), finding in each case that the Na abundance is normal or only slightly depleted with respect to the cosmic abundance and that Ca is depleted by a factor ~ 60. Assuming these abundances are invariant and adopting reasonable cloud sizes, he derived T, n_e, and n_e/n_H for 31 other clouds. The purpose of this letter is to point out that according to Pottasch's model more than half the clouds would produce Ca I absorption different from that observed. In many cases the discrepancy may be insignificant, but for the clouds listed in Table 1 it exceeds a factor of 3.

The first 5 entries in Table 1 are clouds which Pottasch finds to be H II regions. They must have $T \gtrsim 10^4$ °K, so that collisional ionization of Na I accounts for the low Na I to Ca II ratio; and they must be dense enough to account for the strength of the Na I and Ca II lines, while sufficiently ionized that the 21 cm line of H I is very weak. Under these conditions dielectric recombination, proceeding at the rate calculated by Pottasch (1972a), should successfully compete with photoelectric and collisional ionization to produce a detectable concentration of Ca I; but the resonance line λ 4226 of Ca I has not been detected toward any of these clouds. Furthermore, these H II regions would emit significant amounts of Hα radiation. Reynolds *et al.* (1973) searched for this emission, and set upper limits far below Pottasch's prediction for three of the clouds in Table 1. They did not observe exactly in the direction of the stars, and so they could not exclude that the ionized regions might be only a few parsecs in extent. But in that case the electron densities must be larger, which would increase the discrepancy between the predicted and observed Ca I absorption. Very large ionized regions could have lower electron densities and produce weaker Ca I absorption and Hα emission. But to have escaped detection the clouds must be hundreds of parsecs in extent, and not even the luminous O and B stars in whose spectra the interstellar lines are seen could ionize such large regions.

Ca I absorption has now been detected toward other stars in Pottasch's list: ζ Per, β Sco, 32 Peg, and possibly o Aqr[2]) (White, 1973), and only toward ζ Per does his model correctly predict N(Ca I). The data for the other clouds is given in the last three rows of Table 1. As Pottasch discussed, the physical conditions he derived for o Aqr and 32 Peg are very sensitive to the adopted abundances, and to be consistent with the width of the 21 cm line, these two clouds should be assigned temperatures $\sim 10^2$ °K. Then, as in the β Sco cloud, the predicted Ca I column density becomes much smaller than observed.

Adopting an alternative approach to the discrepencies for β Sco, o Aqr, and 32 Peg, one may take the observed column densities and the knowledge that the cloud temperature is low, and derive the Na and Ca abundances as Pottasch did initially:

Star	v (km s^{-1})	[Na/H]	[Ca/H]
ζ Per	+7	13×10^{-7}	1.7×10^{-9}
β Sco	+3	0.29×10^{-7}	0.57×10^{-9}
o Aqr	+6	0.86×10^{-7}	3.1×10^{-9}
32 Peg	+4	0.42×10^{-7}	2.5×10^{-9}
Pottasch average		6.0×10^{-7}	2.5×10^{-9}

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1) For simplicity we shall refer to all the line forming regions as clouds.

2) The signal to noise ratio is 2.4. This discussion assumes that the line has been detected.

Table 1. Clouds showing significant disagreement between predicted and observed Ca I absorption

Star	V_{LSR} (kms^{-1})	[Na I/Ca II]	N(Ca II) ($\times 10^{-11}$ cm^{-2})	N(H I) ($\times 10^{-20}$ cm^{-2})	ΔL (pc)	T (°K)	n_e (cm^{-3})	N(Ca I) ($\times 10^{-9}$ cm^{-2}) Predicted[a)]	Observed[b)]	Observe
ξ Per	+ 21	0.09	2.2	0.14	15	13350	2.4	26	< 4	1
					50	14100	1.0	19		
λ Ori	− 6	0.21	9.5	1.0	15	11300	7.1	250	< 33	2
					50	11950	2.7	180		
ρ Leo	+ 14	1.1	2.6	< 0.1	15	8900	2.7	82	< 3.6	3
					50	9200	1.1	43		
HD 199478	+ 43	0.13	8.	< 0.1	15	12500	7.6	140	< 33	2
					50	12600	2.7	120		
HD 199478	+ 61	0.45	11.	< 0.1	15	9900	10.0	520	< 33	2
					50	10100	3.5	360		
β Sco	+ 3	6.0	4.0	8.4	15	200	0.015	0.18	4.3	3
					50	200	0.015	0.18		
o Aqr	+ 6	3.1	3.6	1.4	15	7450	1.6	56	≤ 3.6	3
					50	7500	0.84	31		
32 Peg	+ 4	2.3	7.5	3.4	15	8100	1.8	160	11	3
					50	8150	1.1	100		

a) Derived using recombination, photoionization, and collisional ionization rates given by Pottasch (1972a, b).
b) Derived from the observed equivalent widths assuming the lines to be optically thin.

1. Hobbs (1971).
2. Adams (1949). Limits were obtained under the assumption that the detection threshold in m Å was three times the reciprocal dispersion of the spe measured in Å mm^{-1}.
3. White (1973).

The large variation of [Na/H] weighs heavily against the hypothesis of constant abundances. However, since the three low values of [Na/H] are based on D-line column densities and the others are based on λ 3302 column densities, it is possible that the apparent discrepencies result from systematic errors in the column density determinations (Nachman and Hobbs, 1973). This seems unlikely, as Pottasch took pains to avoid such systematic errors; but the directly measured abundances might still be consistent with his hypothesis.

In any event, Pottasch's attempt to explain the observed variation in [Na I/Ca II] assuming that the interstellar Na and Ca abundances are invariant results in predictions which conflict with observations of Ca I absorption and Hα emission. Revision of the theory on the basis of newly calculated values of the ionization coefficients (de Boer *et al.*, 1973) fails to resolve the conflict. Unless dielectronic recombination proceeds much more slowly than calculated by Pottasch, the discrepancies between the theoretical predictions and the observations probably imply that his hypothesis is invalid and that the large variation of [Na I/Ca II] results, at least in part, from actual variations in the interstellar abundances of Na and Ca. Abundance variations for other elements in the interstellar gas have been firmly established by observations made from the *Copernicus* satellite (Morton *et al.*, 1973). The range of Na and Ca abundances has been discussed by White (1974) under the assumption that the ionization conditions are similar in all interstellar clouds.

Acknowledgement. The author wishes to thank Dr. Pottasch for a number of helpful comments on this paper.

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